Late Holocene Vegetation History of the Sacramento - San Joaquin Delta, California

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INTRODUCTION

For several years there has been an increasing interest in the reconstruction of past environments of central California. The chief method of research employed thus far has been pollen analysis, or palynology, utilizing mainly material from archeological deposits. Various workers (Matson 1970; Johnson 1976; Hatoff 1977; Kautz 1977), including myself, have attempted to obtain fossil pollen from several archeological sites in the ~~lower~~ Central Valley. The results have been largely inconclusive, due to poor preservation of the pollen; and, even when pollen is recovered, interpretations are hampered by prehistoric anthropogenic influences on the local vegetation. Similar results from archeological sites in the Sierra and Coast Ranges indicate that the pattern of poor preservation and/or anthropogenic disturbance is fairly consistent throughout central California.

Because of the difficulty in obtaining pollen from archeological contexts in the Central Valley and problems in interpreting it when it is recovered, an attempt was made to find sedimentary basins on the valley floor where pollen might be preserved with minimal anthropogenic disturbance. Several sedimentary basins were examined; however, only the results from the Sacramento-San Joaquin Delta are reported upon here. The natural organic deposits in the delta contain well-preserved pollen as well as opal phytoliths, diatoms and other plant remains. These deposits have the advantage of spanning the last 6,500 years, of having accumulated in situ, of being directly datable, and of containing a record of the local environment. However, unequivocal evidence of changes in the regional environment have not been noted, except for those that occurred in the most recent historic past. The data presented are still of considerable importance in dealing with some of the problems in the interpretation of fossil material, namely (1) dispersal of pollen of different species, (2) minor changes in water level, (3) successional patterns of aquatic-emergent vegetation (hydroseres), (4) aspects of the vegetational and evolutionary history of the delta, and (5) disturbance of native plant communities by human interference. Clarification of the latter two problems not only is relevant to central California archeology, but will be useful for planning the future use of the delta.

Location

The Sacramento-San Joaquin Delta lies in the Central Valley at the confluence of the two large rivers from which it takes its name (Map 1). The westernmost point of the delta is 65 km. east of San Francisco; the area extends north up the Sacramento River to a point within 32 km. of the City of Sacramento and southeastward up the San Joaquin River to a point within 16 km. of Tracy. For the purposes of this report, the delta is the area delimited by the one-meter contour line, made up of peat and organic-rich deposits. Roughly triangular in shape, this area contains over 200,000 ha. of organic-rich deposits. At the borders of the delta, the organic soils merge gradually into adjacent mineral soils, or feather out on top of adjacent mineral soils. The central portion of the delta is a complex of islands and meandering channels of the two major rivers; at the western edge of this area the base of the organic deposits extends to over 15 m. in depth, becoming shallower towards the east.

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Environment

With minor exceptions, the entire delta has been reclaimed through an extensive system of man-made levees. During the past 120 years more than 50 tracts and islands have been reclaimed and brought under intensive cultivation. Prior to reclamation the entire area was covered with freshwater marsh. All the major river channels originally were bordered by natural levees (Gilbert 1917; Thompson 1958) standing 2-6 m. above the local land surface which was at sea level. Annually during the winter and spring the levees proved insufficient and the adjacent lands were flooded. In abnormally wet years large areas were inundated, producing a vast shallow lake 20-25 km. wide. The immense sheets of water were broken only by occasional high levees and natural knolls. The levees, formed of alluvial deposits, created a rim around some of the delta islands, and in some instances were covered with dense riparian growth (Thompson 1961), while the central portions of the islands supported extensive freshwater marshes where most of the organic deposits accumulated.

Although the effects of tidal fluctuations are felt inland as far as Stockton and Sacramento, the delta water is fresh; however, prior to the operation of the reservoirs of the Central Valley Project, salinities of 1,000 ppm chlorides occasionally extended as far upstream as Courtland on the Sacramento River and Stockton on the San Joaquin River during the summer and early fall months. Salinity intrusions this high generally are found only in the westernmost portion of the delta today (State of California 1971). It is assumed that in prehistoric times salinity conditions resembled those before the development of extensive man-made dams, that is, increasing salinity with decreasing seasonal flow, highest during the late summer and early fall and accentuated in years of low stream flow. The delta receives drainage from over 150,200 km^2, or nearly one-quarter of the surface area of the entire state. This drainage is restrained temporarily in the delta before passing on a westward course through the relatively narrow Carquinez Strait, its single outlet to the sea via the San Francisco Bay. Under natural conditions delta outflow averaged over 5,500,000 acre feet during March and April, dropped to below 250,000 acre feet in September (McCullough 1972).

Presently, the delta area has a Mediterranean type climate with hot, dry summers and cool, moist winters. During the summer months cool ocean breezes blowing inland through the Carquinez Strait reduce temperatures somewhat below those of other parts of the Central Valley. The mean annual temperature is about 18°C; it is between 9.5°C and 10.5°C for the three winter months and between 21° and 22° for the three summer months. The average frost-free season is almost ten months long. Mean annual precipitation is between 300-350 mm. During the winter months the delta, along with the entire Central Valley, experiences frequent periods of ground or "tule" fog, lasting from a few days to several weeks. This fog is the result of a temperature inversion under a static or stagnant high-pressure area. The layer of fog generally is not over 300 m. thick although at times it may be as much as 600 m. Temperatures during "tule" fogs have a narrow diurnal range, sometimes as little as one to two degrees C; there is little wind movement accompanying the fog. No long-term weather records exist for the delta; however, records from Antioch on the western border of the delta and Stockton on the southeastern border give an approximation of the climate. The mean monthly records for these cities have been summarized in Figure 1. Although minor variations in climate between one part of the delta and another are present, they essentially are insignificant and leave no recognizable imprint on the soils or vegetation.

One hundred and fifty years ago the delta was a vast tule marsh rich in wildlife. The purer and denser stands of tule occupied the central part of each island, where shallow water covered the surface for most of the year. On levees and smaller ridges formed from mineral deposits, tules were replaced in part by a cover of reeds, sedges and woody hydrophytes. In the small ponds and shallow lakes formed in oxbows, water lilies, pondweed and other associated water plants were common. Today, however, there are only remnants of these plant communities. By 1920 practically the entire delta had been reclaimed by a complex of dikes, levees, tidal gates and drainage ditches. In the initial stages, the levees were constructed mainly of organic materials. These small weak levees often failed and areas had to be redrained and levees repaired every few years. Levees today most commonly are constructed with mineral materials obtained by large floating dredges from the bottom of stream channels. Flooding now is prevented by the build-up of the levees and thus the annual inundations which deposited fine-grained sediments and supported dense stands of tules no longer occur. Agricultural practices have lowered surfaces by (1) oxidation of peat after exposure to drying, (2) burning of peat soils, (3) wind erosion of loose dry peat soils, and (4) localized compaction by heavy farm equipment (Weir 1950). Mainly as a result of these reclamation processes and agricultural practices ~~the central~~ portions of many of the former tidal islands are now 3-6 m. below sea level.

The general evolution of the Sacramento-San Joaquin Delta appears to have been controlled mainly by sea level changes related to Pleistocene climatic events and subsidence (cf. Shlemon and Begg 1975). During periods of glacial maximum, sea levels may have been as much as 100 m. below today's (Flint 1971). Since the last glacial maximum (ca. 15,000 B.P.), sea level has increased to its present height. Initially there occurred a relatively rapid rise of approximately 2 cm/year between 9,500 and 8,000 years ago, slowing to approximately 0.1-0.2 cm/year for the last 6,000 years (Atwater, Hedel, and Helley 1977).

It is suggested, based on borehole investigations in the San Francisco Bay, that 8,000 to 10,000 years ago tidal marshes were restricted to a narrow discontinuous band at the margins of an expanding estuary (Atwater, Hedel, and Helley 1977). In the westernmost portion of the delta (Sherman Island) organic clays and silts 17 m. below sea level date some 10,500 radiocarbon years ago (Shlemon and Begg 1975). The earliest evidence, so far, of peat formation in the delta, however, is a radiocarbon date of 6,880 B.P. obtained from a basal peat deposit 15.2 m. below sea level at Sherman Island.

By radiocarbon dating a series of basal peats along an east-west borehole transect through the delta, Shlemon and Begg (1975) have arrived at a first-order indication of the time and rate of sea level rise. They argue that the delta expanded and contracted throughout the Quaternary, responding primarily to glacio-eustatic fluctuations, and related changes in the hydrologic regimen of traversing streams, and that the present delta is a recent geologic feature, having formed over the last 10,500 years (Map 2). However, evidence of Pleistocene channels at 95 m. below sea level found under the delta conflicts with the depth of only 55 m. for the bedrock notch at Carquinez Strait. This

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relationship, Shlemon and Begg suggest, is due to late Quaternary subsidence of the delta and possible uplift of the Carquinez Strait and western Sherman Island. There are know faults crossing the delta, but their surficial expression is minimal or absent (Schlocker 1970). The post-glacial sea level record developed from the San Francisco Bay (Atwater, Hedel and Helley 1977), however, would suggest that the initial stages of the modern delta began about 6,000-6,500 years ago, roughly the same age as Shlemon and Begg's lowest dated peat.

Vegetation - ca. 1850

The distinctive configuration of the delta and associated hydraulic regimes are correlated in turn with a number of distinct biotic communities. One aspect of this study was isolating and obtaining information concerning the pollen rains of these various communities so that they might be characterized and utilized as a guide in the interpretation of fossil remains. Although the delta, as noted, has been greatly altered by man during the last 120 years, it still is possible to find small areas of excellent, though perhaps not pristine, examples of the various communities. Five of these, the Riparian Forest, Oak Woodland, Valley Grassland, Freshwater Marsh and Salt Marsh were of paramount importance in the delta and neighboring areas.

The only true forests of the Central Valley were the Riparian Gallery Forests which lined portions of the major rivers (Jepson 1893; Thomson 1961; Stebbins and Taylor 1973). Located on the natural levees of such channels, these forests formed a dense, multistoried vegetational community with greater niche diversity than any other native ecosystem. Stands of climax Riparian Forest were typified by a dense crown cover and thick understory. The community can be subdivided further into at least nine habitats, based on elevation in relation to that of the river, the amount of flooding and the substrate. Tall cottonwoods (*Populus fremontii*), valley oaks (*Quercus lobata*), walnut (*Juglans hindsii*), California sycamore (*Platanus racemosa*) and Oregon ash (*Fraxinus latifolia*) formed the deciduous canopy with white alder (*Alnus rhombifolia*), box elder (*Acer negundo*) and elderberry (*Sambucus mexicana*) dominating the sub-canopy. The understory was a dense mixture of willows (*Salix* spp.), lianas, grapevines (*Vitis californica*) and numerous tall herbaceous forms.

It is the nature of flood plain environments that river channels are always changing shape and form and that riparian vegetation changes accordingly. A series of successional stages develops initially on bare fluvial deposits and ends in a mature forest. Thus, the floral and faunal composition of riparian communities is diverse and changing over a relatively short period of time.

Extensive wood cutting and clearing for agriculture virtually has eliminated the Riparian Forest in the delta and its immediate environs. In the late 1800's this community served as a ready supply of wood for steamships navigating the river systems and by the turn of the century most of the forest had been eliminated (Thompson 1961).

On the periphery of the delta were Oak Woodland and Valley Grassland communities. The oak Woodland community, usually associated with alluvial mineral soils paralleling the Riparian Forest, in some areas formed bands 3 to 5 km wide. The dominant arboreal form was the valley oak, although box elder and Oregon ash also were common. The Oak Woodland had only a sparse understory, consisting of poison-oak (Rhus diversiloba), elderberry, buckeye (Aesculus californicus), wild rose (Rosa californica) and a few other woody genera. The herbaceous layer of the understory was similar in composition to the Valley Grassland, but with increased abundance of wild rye grass (Elymus triticoides), one of the few rhizomatous grasses common to the Central Valley (Stebbins and Taylor 1973). It is thought that this grass formed a sod in some of the Oak Woodlands (Clements and Shelford 1939). The openness of this community probably was accentuated further by aboriginal burning practices, but specific proof is lacking (Lewis 1973). By the 1870's many large stands had disappeared (Thompson 1961), and today the community is almost extinct.

The Valley Grassland or Central Valley Prairie formerly flanked the Oak Woodland on areas surrounding the delta and extended into the lower foothills. It also was restricted to alluvial mineral soils. Perennial bunch grasses such as needle grass (Stipa spp.), blue grass (Poa spp.) and three-awn (Aristida spp.) were the dominant species. These grasses have completely disappeared from the large areas they formerly occupied and have been replaced by introduced grasses, forbs or cultivated plants (Burcham 1975; Barry 1972).

Of particular interest in the Valley Grassland are the vernal pools or the so-called hogwallows, closed depressions that fill with water during the winter. As the pools begin to dry up in the spring, various annual plants begin to flower, providing a carpet of color where they occur (Ornduff 1974). A floristic analysis of nearly 200 species known to be restricted to, or commonly associated with, vernal pools shows that 91% of the species are considered native to California, a sharp contrast with the surrounding grasslands (Holland 1976:12). Among the 22 genera typical of this community, the families Compositae, Gramineae, Lobeliaceae, Scrophuliaraceae and Marsileaceae have two or three genera each represented prominently in the vernal pool vegetation (Jain 1976).

Freshwater Marsh covered the largest area of the delta. Called "Tulares" by the early explorers, the Marsh community has never been described in detail, although it was once one of the most widespread ecosystems in the state. The lowest-lying terrain in the delta (approximately at sea level), the Marsh periodically was flooded and retained standing water (in some cases affected by tidal fluctuations) throughout most of the year and was dominated by tules (Scirpus spp). It also contained cattails (Typha latifolia, T. angustifolia, T. domingensis, T. X Glauca) (Hotchkiss, Niel and Dozier 1949), sedges (Carex spp.), rushes (Juncus spp.), reeds (Phragmites communis) and other marsh plants. A number of aquatic species also were common in areas such as oxbows that had deeper permanent water. Pondweed (Potamogeton spp.), yellow pond lily (Nuphar polysepalum), Ludwigia peploides, knotweed (Polygonum spp.) and wapato (Sagittaria latifolia) commonly were present. When compared with most other plant communities, the delta Freshwater Marsh was one of relatively low species diversity, and vast tracts of marshland were covered with almost pure stands of tules.

In the westernmost part of the delta are several islands that still contain areas representative of the oligohaline phase of Freshwater Marsh. California bulrush (Scirpus californicus) is dominant, forming almost pure stands in some localities. Cattail (*T. domingensis*) and reed (*Phragmites communis*) are also common. This is one of the few relatively undisturbed communities in the delta.

It is from the marsh plants that peat and organic mucks have formed. Tules and cattails are the primary organic components of the peats and peaty mucks. Some organic mucks, on the other hand, have a large fraction of finely divided organic debris derived from plant life associated with deeper or more open water conditions. Numerous borings reveal layers of peat and organic mucks interspersed with light-gray or bluish-gray fine-grained fluvial, estuarine and lacustrine deposits.

Two hypotheses have been offered regarding the development of Delta peat deposits. One is that the peat was formed by the settling out of floating peat mats in deep water (Dachnowski-Stokes 1936); the other is that the peat developed at or near sea level, with continual building during a period of regional subsidence (Cosby 1941). Shelmon and Begg (ibid) note that there is evidence supporting both hypotheses in the delta today, but that the major factor involved in the latter hypothesis was post-glacial sea level rise and not subsidence, as Cosby assumed.

Although extensive Salt Marsh communities formerly occurred in the more protected of the tidal zones west of the delta, these areas have since undergone considerable alteration. Low marsh surfaces today are dominated by cord grass (*Spartina foliosa*) and tules (predominantly *Scirpus californicus*), while in the higher marsh pickleweed (*Salicornia pacifica*) and salt grass (*Distichlis spicata*) are dominant. *Salicornia* extends from about the extreme high tide line down to about the average, or mean, high tide line. In this zone, *Salicornia* often grows in almost pure stands (Jurek 1978). Salt marshes that have the greatest magnitude in salinity, such as those found closer to the delta, are inhabited by as many as 30 species, whereas those marshes near to, or in, the San Francisco Bay are typically occupied by 10-15 salt-tolerant species (Atwater and Hedel 1976).

METHODS

The objectives of this research project necessitated a multidisciplinary approach. Initially botanists made on-the-ground and areal surveys and wrote brief descriptions of the major plant communities in the delta and its environs. This data, some of which has been summarized above, is a basis for the reconstruction of past environments. Core samples were collected and have been analyzed for sediment size and composition and for identification of diatoms and other macro- and micro-plant remains. The major emphasis is, however, on pollen.

Sampling

Initial work for the pollen studies, in conjunction with the botanical surveys, was the collection of surface samples of the modern pollen rain from selected plant communities. Collection was undertaken by multiple-pinch (200) surface samples (Adam and Mehringer 1975) of the uppermost layer of the soil or, in aquatic environments, by 2.5 cm. diameter cores from which the sediment/water interface was recovered. All samples were collected during the winter to avoid over-representation from plants undergoing anthesis. Plans originally included the collection of the suspended fraction of stream load during periods of high flow, but no high flows occurred during the 1976-77 seasons. Over thirty samples were examined from different communities and depositional environments (Map 3). In one locality, South Stone Lake, sediment/water interface samples were taken as a transect covering several habitats to gain a clearer understanding of the relationship between vegetation as represented by its pollen, varying water depth and substrate.

Selection of coring localities was made after inspection of cores and core logs collected by the Department of Water Resources for the Delta Peripheral Canal Project. Renewed coring was undertaken in those areas where there was evidence of organic deposits (Map 3). Elevations of the boreholes were determined by leveling from National Geodetic Survey bench marks, or, in the case of the Clifton Court locality, from settling gauges maintained by the California Department of Water Resources.

Two different coring devices were used to obtain the fossil samples. The first, a hydraulically-pushed unit called a "Giddings-Drill-Corer", was used for the coarser sediments which could be reached by a pick-up truck and trailer. The other device was a hand-operated, modified Livingston piston corer (Livingston 1955), used in soft sediments from the transom of a small boat. Although longer cores could be obtained with the Giddings rig, they were more distorted than those obtained with the Livingston rig. Both corers produced cores approximately 5 cm. in diameter. After collection, cores were frozen and stored until ready for processing.

For pollen analysis, uniform size samples were taken from the cores in 2 cm. intervals, weighed and then prepared according to methods outlined by Mehringer (1967) and Faegri and Iversen (1975). A portion of the extracted residue was then mounted with "Clearcol", a water miscible mounting medium which has an index of refraction of approximately 1.435. Counting was done with a Nikon L-Ke microscope with phase contrast using 15X eyepieces and 40X or 100X objectives. Reference material to aid in identification was prepared from herbarium specimens from the Botany Department, University of California, Davis. Reference slides from the Paleontology Department, University of California, Berkeley also were used as was Kapp (1969).

Pollen Types

Arboreal pollen types in modern samples and the fossil record can be referred to: pine (Pinus); fir (Abies); alder (Alnus); willow (Salix); walnut (Juglans); ash (Fraxinus); birch (Betula); cottonwood (Populus); maple or box elder (Acer); and oak (Quercus). The category TCT, including the families Taxodiaceae, Cupressaceae and Taxaceae, probably consists mainly of incense cedar (Libocedrus), juniper (Juniperus) and redwoods (Sequoia spp.); some nutmeg or yew (Taxus spp.) and cypress (Cupressus spp.) also may be present (Adam 1967). Pollen types of non-arboreal plants can be referred to as grass (Gramineae), Cheno-Ams (Chenopodiaceae and the closely related genus Amaranthus), Rhamnaceae-wild grape (Rham.-Vit.), common cattail (Typha latifolia), cattail/bur-reed (Typha/Sparganium) and sedge predominantly the genus Scirpus (Cyperaceae). The Compositae is divided into four groups: the genus Artemisia, the subfamily Liguliflorae, and the high-spine and low-spine Compositae, both within the same subfamily Tubliflorae (Adam 1967). Pollen grains with spines greater than their basal widths are classes as high-spine types.

As noted above, in the delta today three species of Typha are found as well as their hybrids. Typha pollen in the cores and surface samples was recognized in three forms: tetrads, dyads and monads. These have been plotted separately on the diagrams. The tetrads are referable to T. latifolia, and the monads to either T. angustifolia or T. domingensis, though T. domingensis also produces dyads (Mason 1969; Hotchkiss and Dozier 1949; Smith 1967). However, the hybrid Typha X glauca, a cross between T. latifolia and either of the other two species, produces pollen in tetrads, dyads or monads, and individual plants will produce varying amounts of the different types. Crosses between T. angustifolia and T. domingensis, which appear to be restricted to California populations, produce monads. It is also possible that some of the monads identified as Typha are referable to Sparganium since they are virtually indistinguishable with a light microscope. Sparganium, like Typha, is found throughout the delta and prefers the mucky bottoms of shallow ponds, sloughs and the edges of slow moving streams.

RESULTS

Modern Stone Lake Transect

Diagram 1 shows the various pollen spectra of a transect made across South Stone Lake which is a remnant of an ancient stream channel, probably an oxbow, some 20 km south of Sacramento. The lake today is surrounded by farmland to the north and marshland to the south. A description of the vegetation has been completed by Macdonald, Conard and Holland (1977). Prior to levee protection the lake was subject to flooding or high water tables during river overflow. From 1917 to 1937 the lake was drained and the land planted to beans, but after this period the lake was re-flooded and the natural vegetation has been allowed to reestablish itself. The perturbations, however, may have allowed many exotic species to become established and consequently some of the native flora undoubtedly was lost. Since pollen analysis at present allows for only a generalized view of the vegetation, it is felt that the present pollen rain, despite environmental disturbance, is significant and therefore useful for interpreting the fossil record. This is, of course, not an ideal situation but one that must be dealt with when examining _any_ aspect of modern plant communities in California.

Accumulations of organic debris occur only under _Scirpus-Typha_ and, in lesser amounts, _Polygonum-Ludwigia_ habitats. Open water habitat substrates are silts and clays.

As illustrated in the diagram, the modern pollen rain is indicative of the plant habitats. The stands of _Scirpus_ have Cyperaceae-type relative pollen rain values between 34 and 53% (averaging about 41%), which drop off rapidly to an average of 19% when moving from dense stands to open water. Though there are no natural growths of native pines on the valley floor, pine values show relative increases in the deeper, more open water where the absolute abundance of pollen drops. The pine pollen obviously is being transported from higher elevations, mainly the Sierra Nevada, by wind and water. Of all the surface samples collected on the valley floor, pine has a value of around 5% and this too is reflected in the diagram. Heusser and Balsam (1977) found in a study of modern marine sediments west of San Francisco that pine percentages increase seaward, from less than 10% of the pollen sum in shelf sediments to over 50% in sediments on the abyssal plain. They suggest that this indicates selective transport of pine pollen. In addition, the absolute amount of pollen decreases in the abyssal plain sediments and shows a general decrease with distance from shore. Pine values this high also were recorded for surface samples collected in the Sierra Nevada foothills where pine is common (Adam 1967). Oak, though present locally, also shows a relative increase in the open water. The distribution of _Typha_ and _Salix_ pollen is similar to that of _Scirpus_ though their relative values are proportionally lower. _Typha_ is common along the transect but in this instance does not form exclusive stands. High-spine Compositae, grass and Cheno-Ams appear to have an inverse relationship of _Scirpus_ values. Polygonaceae pollen shows a sharp rise in value at the contact between _Scirpus-Typha_ and the _Polygonum-Ludwigia_ zones, and then drops off to much lower values. The high Polygonaceae value (at sample 4) appears anomalously high. _Nuphar polysepalum_, _Ludwigia_ and Polemonaceae, though of low relative values because of low pollen production, are distinctly present. The pollen of introduced plants such as Eichornia (Water Hyacinth), Zea Mays (corn) and Eucalyptus also is present. Pollen from populus (cottonwood) and Juncus (rushes) occur in extremely low values considering their abundance, but their pollen does not preserve well (Faegri and Iversen ibid). In addition, Azolla glochida are present in many of the samples.

Other Modern Surface Samples

Some 13 modern surface samples were collected from plant communities in and around the delta (Diagram 2). Four of the samples, from Valley Grassland, Vernal Pools/Grassland, Allenrolfea Alkali Sink and Oak Woodland, are multiple-pinch samples; the others are from the sediment/water interface.

The brackish water (Oligohaline) phase of the tidal Freshwater Marsh is represented by samples from Browns and Joice Islands in the westernmost portion of the delta. Both areas are dominated by tule, though Joice Island is more disturbed and has a greater cover of introduced species, of which brass buttons (Cotula coronopifolia) is particularly important; it also is slightly higher in elevation and is affected only by the highest tides. All three sampling localities in these islands are marked by high relative values of Cyperaceae, ranging from 23 to 45%. The value of high-spine Compositae for the tule marsh border with open water of Browns Island and for Joice Island may be significant. On Joice Island, as noted, brass buttons, a Compositae, is abundant and may account for the relative increase; but no Compositae were observed in the area where the Browns Island sample was taken. It is suggested that the slightly higher values of high-spine Compositae, pine and oak pollen for the tule marsh border are due to slightly lower absolute pollen values, though this assumption has yet to be tested. The second sample from Brown's Island was taken from a dense stand of Scirpus some 10 m. away from the first. This sample came from an area with an organic substrate while the other two had mineral substrates; its most conspicuous feature is the dominance of sedge pollen (45%). Eucalyptus, walnut and milfoil (Myriophyllum) also are present in all three samples.

The South Stone Lake sample came from the contact zone between a mixed tule/willow freshwater marsh and open water. The pollen values for Cyperaceae and willow (Salix) are both relatively high and reflect the composition of the present-day vegetation. All other species, with the exception of oak, have values of 4% or less. Yellow pond lily pollen, though not abundant, is present. Walnut values reach 1%, probably because nearby areas are planted with English walnut (J. regia) orchards. The substrate is organic muck under approximately 90 cm. of water.

A lake sediment sample was collected from Big Buttonwillow Lake in the Los Banos Wildlife Area. The wildlife area is a remnant of the maze of ponds and marshes that once made up the San Joaquin Sink. Today the area supports alkali grassland, dominated by alkali sacaton (Sporobolis airoides) a large perennial bunch grass, with iodine bush (Allenrolfea occidentalis), gum plant (Grindelia sp.) and several species of rushes (Juncus spp.) as associates. Marsh sites support nearly pure stands of cattail except on higher ground where button willow (Cephalanthus) thickets occur. Several well-developed alkali vernal pools also are present. Cheno-Ams and Typha monads are the most abundant pollen types, though Salix reaches almost 10%.

The multiple-pinch surface sample taken from the Alkali Grassland Community at Los Banos Wildlife Area is characterized by high Cheno-Am (39%) and high-spine Compositae (26%) pollen values. Grass values are relatively low; but this is due most probably to the greater pollen production by the Cheno-Ams and Compositae.

The Allenrolfea Community at the Los Banos Wildlife Area is marked by Cheno-Am values of 55%. Compositae pollen values account for 20% of the remaining species represented. The latter values and the low Gramineae value (3%) help to distinguish this Chenopodiaceae-dominated community from the Salicornia (Chenopodiaceae)-dominated upper tidal Salt Marsh Community, represented by the sample from Suisun Marsh, with a similar Cheno-Am value of 58%, but a Gramineae value of 17%.

At the nearby San Luis National Wildlife Refuge, samples were taken from a marsh dominated by cattails (T. angustifolia): one sample from an area of open water some 70 cm. deep with a mineral substrate; the other from a dense stand of cattail with a slightly more organic substrate and a water depth of 55 cm. The relative value of Typha monad pollen is about 30% in the latter sample, dropping to about 21% in the open-water sample. Low-spine Compositae values are also relatively important, reaching 11 and 14% respectively. Both samples contain Ephedra pollen, with the sample from the cattail marsh having nevadensis and torreyana types represented (Martin 1963). The only Ephedra in the drainage system is the nevadensis-type E. californica which grows along the western edge of the San Joaquin Valley. The nearest occurrences of torreyana-type ephedras are east of the Sierra Nevada and in the lower Mojave Desert (Munz and Keck 1963; Munz 1974). Torreyana-type ephedra pollen has been found in wind-blown dust derived from southern California and collected in Davis, some 20 km. north of the delta (West, unpublished data). English walnut groves and native walnuts growing locally probably account for the 1% Juglans values in the open water sample.

In the uncultivated areas south of Dixon are some of the best remaining examples of Valley Grassland/Vernal Pools in the Central Valley. It was from this area (Hamilton Range) that the Vernal Pools/Grassland sample was taken. The vernal pools are little disturbed by grazing activities, and some contain water year around in wet years. Nearby occurs one of the last remaining relatively undisturbed communities of Valley Grassland. The area has coarse mineral soils, with a well-developed hardpan in the vernal pool area. Compositae pollen values reach their highest frequency here (28%), and although Gramineae is the next most frequent pollen type it only reaches values of about 12%. This again apparently is due to the greater pollen production by Compositae, as well as to their abundance.

To obtain the modern surface pollen rain from a Riparian Forest Community, a sediment/water interface sample was collected from a remnant of an oxbow lake near Princeton, along the Sacramento River. The Princeton locality supports a relatively undisturbed Riparian Forest with several tree and shrub layers. Cottonwood is the dominant tree, with California sycamore and valley oak being subdominants in the slightly higher and drier locations. The pollen sample from this locality is marked by high pine values (14%) and by a diversity of pollen types, particularly arboreal species. Walnut reaches a value of 3.3%, due probably to the presence of nearby English walnut groves. There is also a relatively high percentage of undifferentiated pollen present in the sample.

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The Oak Woodland surface sample is most distinct, with high relative values of oak (30%) and grass (33%) pollen. The Cosumnes River locality from which the sample was collected supports excellent examples of relatively undisturbed Valley Oak Woodland (Stebbins and Taylor ibid); the pollen rain tends to reflect this lack of pertubation in that there is only a minimal occurrence of the pollen of plants commonly associated with disturbance.

FOSSIL RECORD RESULTS

The pollen record for the delta is based on data from two cores along the proposed route of the peripheral canal and from spot samples of dated deposits in the western part of the delta. From radiometric dating of peaty mucks it has been determined that approximately 5,000 years is represented in the cores examined. Nearly all of the samples examined are characterized by high relative values of the pollen of aquatic-emergent plants. In most cases the pollen was abundant and well preserved in the peats and peaty mucks, but in the mineral sediments pollen as poorly preserved, scanty or nonexistent. Some fifty different pollen types were identified, while the unidentified types averaged about 10% of the total. Photomicrographs of some of the pollen grains as well as seeds are shown in Figure 2.

The pollen diagrams are broken where the sediments lack pollen or there is an erosional contact, or where core samples were not recovered. Percentages for each pollen type are based on the total pollen count, including unknowns, and are plotted on the diagrams as such. A dot (.) indicates that a pollen type is present at less than 1%, unless otherwise noted. Radiocarbon ages (Table 1) are plotted as to their stratigraphic position on the pollen and sea level diagrams. All dates were obtained from organic-rich deposits which came from the phreatic zone, and in all but one case they were taken from under silt or clay layers which had not been penetrated by contemporary rootlets.

Clifton Court

A 3.5 m. core was recovered from Clifton Court in the southeast corner of the delta (Map 1). From radiometric dating of the basal organic muck, it has been determined that the core spans a period of over 4,500 years, although it is doubtful that this represents a continuous record. The sediments are described in Table 3.

The bottom of the lowest organic layer is dated at 4,340 ±150 BP and the top at 3,940 ±140 BP. This represents an accumulation of organic debris, not accounting for compression, of 28 cm. in 400 years, or roughly 7 cm/century. The lowest radiocarbon dated sample, however, may be somewhat older than indicated, since the roots and rhizomes of younger age plants may have intruded into the sample (Kaye and Barghoorn 1964). Consequently, the calculated accumulation rate may be exaggerated.

The upper boundary of the lower organic muck grades into a medium-gray silty clay with a relatively high organic content. The overlying light-gray silty clay (as noted by a break in the pollen diagram) did not contain sufficient pollen for analysis; however, some of the pollen present appeared to be well preserved. At the top of the light-gray silty clay there is a transitional layer to a peaty muck. The base of the peaty muck has been dated at 2,950 ±150 BP. Above the peaty muck is a thin layer of yellow-brown silty clay grading into a dark-brown organic soil.

Beginning again at the base of the profile, with a consideration of the pollen record, the changes appear to be successional; high relative values of Polygonaceae and _Salix_ being replaced by Cyperaceae. Most of the Polygonaceae appear to be tricolporate with a transverse furrow and prolate. The exine is thick and tectate, with stout columellae which form a distinct reticulate pattern. Polygonum, though eurypalynous, is the genus must likely represented (Figure 2). The presence of abundant Scirpus seeds suggests that Scirpus is the dominant Cyperaceae pollen type. Cyperaceae values are high throughout the lower section of the core, but decline sharply at 340 cm., with increased values of Salix and Pinus. The pine values of almost 35% are the highest for any sample from the delta. The only other occurrences of high relative pine values were in the Riparian Forest (14%), the South Stone Lake open-water modern surface sample (24%) and the Sierra Nevada Foothills (Adam 1967). Thus, it is not clear whether the increase in pine pollen represents a regional environmental change which is the result of a climatic change or is merely a relative change due to variation in pollen accumulation. Nuphar pollen, while not abundant, is present. Of the arboreal types, the presence of Juglans is notable.

The minimal occurrence of pollen and diatoms in the light-gray silty clay and the increase in the percentage of sand (40%) suggest that deposition took place quite rapidly. The lack of organics suggest open-water conditions much like those found today at South Stone Lake. It also is probable that before the silty clay was deposited, erosion took place, removing an unknown amount of the lower organic deposit. Finally, it is most probable that the light-gray clay layer was deposited shortly before 2,950 ±150 BP, which is the radiocarbon date for the lower border of the peaty muck.

The lower samples of the upper organic section initially have high relative values for Polygonaceae and, though not as high as in the lower section, of Salix, suggesting the beginning of a successional sequence. The upper organic section is somewhat different from the lower, having higher values for Typha latifolia, Typha monad, Nuphar and Polemonaceae, and lower values for Salix and Pinus. Most striking is the increase in Typha pollen, particularly T. latifolia, and the latter's abrupt decline where a change in sediment occurs. Thus, it is possible to assume that shortly after 3,000 years ago the immediate area was frestwater marsh again but that the relative composition of the flora had changed noticeably. Cyperaceae values, however, still account for the major fraction of the pollen spectrum, and tule was probably the dominant plant.

As noted, there are difficulties in the interpretation of Typha pollen; keeping this in mind, it is suggested that the change in ratio between T. latifolia and Typha monad is significant. The T. latifolia found today in central California and extending eastward into the Sierra Nevada prefers fresh water and is more common than the other species of cattails in fresh water marshes. On the other hand, T. domingensis and T. angustifolia, which produce pollen in monads, prefer more alkaline environments (Table 2). In the alkaline marshes of the San Joaquin Sink nearly all the Typha pollen occur as monads (Diagram 2). Thus, it may be that the changing ratio between T. latifolia and T. monad is a reflection of water quality.

Beginning at about 45 cm. a change occurs: Cheno-Am pollen values begin to increase, followed shortly by the first appearance of Eichornia crassipes (water hyacinth), a turn of the century introduction from South America (Bock 1968). Increase in Cheno-Am counts often results from agriculture and other anthropogenic disturbances. In addition, many Chenopodiaceae species, such as pickleweed and fat hen (Atriplex hastata), are halophytes which are dominants in the upper tidal portion of salt marshes. It is inferred, however, that since the rise in Cheno-Ams begins slightly before the occurrence of water hyacinth pollen, its increase in the present case is a result of late nineteenth century reclamation in the delta.

Though not noted in the diagram, the glochidia of the microsporangic massulae of Azolla mexicana and A. filiculoides were found in all layers of the core. The glochidia preserve well and can be identified to the specific level; thus they are useful paleoenvironmental indicators. Both species are common in fresh water throughout California (Mason 1969).

Honker Lake

The meaning of the pollen sequence from Honker Lake Tract on Roberts Island is less clear than that from Clifton Court, since the record is very discontinuous (Diagram 3). The sedimentary sequence is also more complex, consisting of several peat or peaty muck layers interspersed between sands, silts and clays. The stratigraphic sequence of the core, however, is similar to that observed at the Clifton Court locality, in that there is a thick lower peaty muck separated from an upper thick peaty muck/organic soil by a silty clay layer. This silty clay layer, like that found at Clifton Court, lacks pollen and organic detritus. In the upper 50 cm. of the core are two burnt peat layers. After reclaiming the peat lands for agriculture, farmers often burned the dry peat to rid the soils of destructive pests; the two burned layers may be indicative of this practice.

The pollen sequence, though dominated by Cyperaceae, is somewhat different. Typha (T. monad and T. latifolia) is relatively important in the lower peaty muck and T. latifolia unimportant in the upper peaty muck. Low-spine Compositae reach high relative values, a pattern opposite that seen in the Clifton Court core. Grass pollen is also of greater importance and reaches values of 19% in two of the samples. Cheno-Am values are very low throughout, except for the uppermost samples which have values of 50, 63 and 38%. These values, like those noted in the Clifton Court record, probably are reflective of anthropogenic disturbance. The presence of Nuphar pollen throughout the profile indicates limnetic conditions (Table 2), as Nuphar will perish rapidly if salty water invades its habitat. It also is possible that the Nuphar pollen was transported downstream, however, there is no evidence to support this assumption. The lower peaty muck layer contains abundant Scirpus seeds. No radiocarbon dates are available for the core, but its lowest organic levels, considering their depth and geographic position, are probably close to 4,500 years old.

The counts of Azolla filicoides to A. mexicana glochidia has been plotted on the right hand side of the diagram. There presence further suggests limnetic conditions supporting the interpretation made from the presence of Nuphar pollen.

Terminous Tract

Spot samples from core taken at Terminous Tract and Sherman Island also were examined. The samples were collected prior to the inception of this project and were provided by Eugene Begg of the Department of Soils and Plant

Nutrition, University of California, Davis. The mineral samples consistently were devoid of any pollen, while the peats and peaty mucks contained sufficient pollen to characterize the vegetation.

A peat sample from Terminous Tract was collected just above a dated contact (3,315 ±150 BP) at approximately 3.5 m; it contained poorly-preserved pollen and Brasenia Schreberi and Polygonum seeds. The value for Cyperaceae pollen is relatively low (21%) while high-spine Compositae (24%) and Gramineae (14%) have high values. Myriophyllum, which has an affinity for alkaline and stagnant eutrophic water conditions, attains a value of 3.2%, the highest noted for this genera in all the samples examined. Typha latifolia and T. monad both are present, but only total 5.5%. Nuphar pollen is present and this would suggest acidic water conditions opposite to those preferred by Myriophyllum.

Sherman Island

Several pollen counts were made of peat layers recovered in a core taken from Sherman Island at a location where the peat deposit is thickest (Map 2). Cyperaceae is the dominant type, with values ranging from 37 to 53%, suggesting a tule-dominated marsh. The next most important pollen type is high-spine Compositae, with values ranging from 7 to 19%. Grass reaches a value of 11% in one sample. Arboreal pollen types are not significant, totaling less than 10%. In one sample Nuphar is present, and two samples contain Azolla glochida, suggesting limnetic conditions.

DISCUSSION

This initial palynological study of the sediments comprising the Sacramento-San Joaquin Delta has produced several conclusions. They are:

(1) The organic deposits contain abundant and in most cases well-preserved macro- and micro-fossil remains.

(2) These deposits are indicative of the former local environments and can be dated by radiocarbon methods.

(3) The modern pollen rain is representative of the community from which it has been collected. In the delta and its environs there are portions of several major plant communities which, while not pristine, are thought to be good examples of the former vegetation, and modern pollen samples derived from them appear to reflect the general nature of the vegetation. In fact, the relationship between the pollen rain, vegetation and substrate is quite good, though further clarifications using absolute abundance of pollen should be undertaken. In the meantime, the modern samples may be used in the interpretation of the fossil material present in the delta sediments. Thus, using a comparative method considering relative and in some cases absolute pollen values and the tolerances of individual species, it has been possible to characterize the vegetation and vegetational changes that are recorded in delta deposits.

(4) From the localities examined it is suggested that the delta has been a freshwater marsh dominated by tules for over at least the last 5,000 years. Stream channels have shifted, altering the local vegetation and initiating hydroseres, beginning with open-water Polygonaceae-dominated environments, which were rapidly encroached upon by tules and cattails. It was from the remains of these latter species that the peat and peaty muck deposits were formed. Not all the hydroseres had exactly similar sequences however; for example, the lower peaty muck at Clifton Court contained little Typha latifolia, while in the upper peaty muck it was abundant. These differences, though, are minor, and probably are reflective of slight differences in elevation in relation to water depth, water quality or migration distances. No evidence was found of reed (Phragmites communis) peat which Cosby (1941) described as being a thick accumulation underlying Scirpus peat. There also was no evidence for salinity intrusions in the areas samples of a period long enough to alter the composition of the vegetation so that it would be reflected in the pollen or macro-fossil record such as Dachnowski-Stokes (1933) noted in Suisun Bay. All the fossil forms identified from the sediments exist in the delta today, while introduced species and evidence of anthropogenic disturbance is recorded in the two core samples quite distinctly. Thus, we may conclude that the composition and relationships of the flora in the delta prior to the mid-1800's has been essentially the same for 5,000 years.

(5) In the areas examined, it appears that the rate of peat and peaty muck accumulation is roughly synchronous with sea level rise in the areas examined (Figure 3) and, though there may be some discrepancies due to subsidence, compaction and other unknown factors, they appear to be minor.

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(6) Dachnowski-Stokes (1933) has argued from borings made on Staten, Bouldin, McDonald, King and Roberts Islands, and the Upper Jones' Tract that at least one great period of silt deposition intervened during the early formation of the delta peat deposits. This is represented by a band of silt, clay and fine sand and is most probably equivalent to the light-gray silty clay layer noted in the Clifton Court and Honker Lake localities. He attributes the layer to a period of cooler-moister climatic conditions which increased the erosional, overflow and transporting power of the Sacramento-San Joaquin Rivers, causing them to drop a load of detritus on the delta. Since the time the Dachnowski-Stokes studies were made, a considerable amount of evidence has been accumulated suggesting a cooler-wetter period beginning approximately 4,000 to 2,500 years ago (LaMarche 1973; Mehringer 1977; Casteel, Adam and Sims 1977; Adam 1967). High relative *Pinus* pollen values (35%) in the peaty muck just below the light-gray silty clay at the Clifton Court locality (dated at 3,900 B.P.) may be representative of this change. A similar relative increase in *Pinus* pollen also was noted in the Honker Lake organic layer that is immediately underlying light-gray sandy silt. It is suggested that the Honker Lake lower organic layer is equivalent in age to the lower peaty muck at Clifton Court. The light-gray clay layer appears, on the basis of the low absolute abundance of pollen and diatoms, to have been deposited in a relatively short period of time. Although these co-occurrences are intriguing, the relationship between them remains to be demonstrated.

(7) The presence of *Juglans* pollen, undoubtedly from *J. Hindsii*, confirms the existence of walnut in central California some 4,500 years ago. Thomsen (1963), in a review of the fossil evidence for *Juglans*, pointed out the lack of a late Pleistocene-Holocene record, and suggested that such evidence in the form of pollen might be found in the delta peat. This study has proven her suggestion correct.

(8) The diatom analysis substantiates the conclusions reached from the pollen data (S. L. VanLandingham, personal communication).

In summary, the configuration of the present-day delta is primarily the result of the effects of sea level change and subsidence occurring since about 6,000 years ago. It has expanded, at least up until recently, in a concentric fashion, increasing in area as sedimentary processes and peat accumulation responded to the rising sea levels and subsidence. In the sediments of the delta is a record of these changes, consisting of mineral and organic deposits containing abundant macro- and micro-fossils of the plants that once lived in and around the delta. Through an examination of these remains and a comparison of this data with modern analogs, it has been possible to infer the environmental conditions of the delta over the last 5,000-6,000 years.

ACKNOWLEDGMENTS

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TABLE 1

Radiocarbon Dated Peats, Peripheral Canal Project

	Locality	Depth Below Sea Level	Date	Lab. Number	Material
A.	Clifton Court	172-177 cm.	2950 ± 150	GX 4221	peaty muck
B.	Clifton Court	340-347 cm.	3940 ± 140	GX 4222	peaty muck
C.	Clifton Court	368-373 cm.	4340 ± 150	GX 4223	peaty muck

TABLE 2

Species (3)	Plant Community	Substrate	Water Depth (cm.)	Salinity	pH	Water Temp. (°C)
Myriophyllum spicatum	Freshwater to brackish sloughs and ponds (3)	Organic ooze, clays and silts (8)	50-200 (8, 15)	Saline-tolerant to 30% sea water (9)	7.5-10.3 (8, 15)	20-30 (8)
Elodea canadensis	Freshwater sloughs and ponds (3)	Soft, deep silts, organic ooze; calcareous (7)	50-250	Freshwater (7)	5.5-8	15-20 (6)
Nuphar polysepalum	Freshwater sloughs and ponds (3)	Organic ooze, clays and silts	80-300	Freshwater (3)	-----	15-25 (6)
Eichornia crassipes*	Freshwater sloughs and ponds (3)	Floating (16)	-----	Freshwater (3)	-----	-----
Ludwigia palustris	Mud borders of fresh-water ponds and sloughs (3)	Silts and sands (14)	Semi-emergent to terrestrial (14)	Freshwater (3)	-----	-----
Navarretia prostrata	Vernal pools (5)	Clays (hardpan) (5)	up to 15-25 (5)	Freshwater (5)	Neutral	-----
Scirpus californicus	Low-elevation fresh to moderately saline marshes (1)	Peats, organic ooze, clays and silts	-----	5-10‰ (2)	-----	-----
Scirpus robustus	Brackish middle-elevation marshes (1)	Peats, organic ooze, clays and silts	-----	Saline 7-32‰ Optimum 22% (1,17)	-----	-----

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Species (3)	Plant Community	Substrate	Water Depth (cm.)	Salinity	pH	Water Temp. (°C)
Scirpus acutus	Low-elevation moderately saline marshes (1)	Peats, organic ooze, clays and silts	-----	5-10‰ (2)	-----	-----
Phragmites communis	Freshwater ponds, sloughs, and marshes (1)	Peats, organic ooze, clays and silts	5-100+ (12)	Freshwater to 2‰ (2)	Neutral (12)	-----
Typha latifolia	Freshwater acidic to neutral marshes, ponds, sloughs and seeps (4)	Peats, organic ooze, clays and silts	5-100+	Freshwater	5.5-7 (4, 11)	-----
Typha angustifolia	Fresh to brackish basic marshes (4)	Organic ooze, peats, clays and silts	5-100	2-20‰ (2, 17)	7-8.5 (4, 11)	-----
Typha domingensis	Saline, alkaline marshes (4)	Peats, organic ooze, clays and silts	5-100	2-10‰ (2)	Alkaline 7-10 (4, 11)	-----
Spartina foliosa	Low-elevation highly saline marshlands and tidal flats (1)	Clays, silts and sands (mud-flats) (1)	Semi-emergent to terrestrial (MTL-MHHW) (1)	Highly saline 15-20‰ and up (1)	-----	-----
Salicornia virginica	Saline high-tidal marshlands and mudflats (1)	Clays, silts and sands (mud-flats) (1)	Semi-emergent to terrestrial (MHHW and above) (1)	10-80‰ (1, 17)	-----	-----
Distichlis spicata	High moderately saline marshlands (1)	Clays, silts and sands (mud-flats) (1)	Semi-emergent to terrestrial (MHHW and above) (1)	12-33‰ or less (1, 17)	-----	-----

Species (3)	Plant Community	Substrate	Water Depth (cm.)	Salinity	pH	Water Temp. (°C)
Atriplux patula	High-level salt marshes (1)	Clays, silts and sands (mud-flats) and terrestrial soils (1)	Terrestrial (3)	Saline (1)	-----	-----
Artemisia douglasiana	Open, dry to moist areas near sloughs or riparian zones (13)	Terrestrial soils (13)	Terrestrial (13)	Nonsaline (13)	-----	-----

*Introduced

MTL - mean tidal level
MHHW - mean high tide level

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FIGURE 2

Common Pollen and Seeds From Delta Peat Cores

1. _Eichornia crassipes_ (Mart.) Solms-Laubach (Pontederiaceae)
2. Polemoniaceae
3. _Rumex sp._ (Polygonaceae)
4. _Vitis californica_ Benth. (Vitaceae)
5. _Lithocarpus sp._ (Fagaceae)
6. _Elodea sp._ (Gydrocharitaceae)
7. _Quercus sp._ (Fagaceae)
8. Cyperaceae (_Scirpus sp._)
9. _Ludwigia peploides_ (HBK.) Raven (Onagraceae)
10. High-Spine Compositae
11. _Juglans sp._ (Juglandaceae)
12. _Quercus sp._ (Fagaceae)
13. _Typha-Sparganium_ monad (Typhaceae-Sparganiaceae)
14. _Polygonum sp._ (Polygonaceae)
15. _Rumex sp._ (Polygonaceae)
16. Umbelliferae
17. _Cuscuta salina_ Engelm. (Convolvulaceae)
18. Chenopodiaceae
19. _Alnus sp._ (Betulaceae)
20. _Artemisia sp._ (Compositae)
21. _Najas sp._ (Najadaceae)
22. _Brasenia sp._ (Cabombaceae)
23. _Scirpus sp._ (Cyperaceae)
24. _Polygonum sp._ (Polygonaceae)
25. _Potamogeton sp._ (Potamogetonaceae)
26. _Daphnia_
27. _Salix sp._ (Salicaceae)

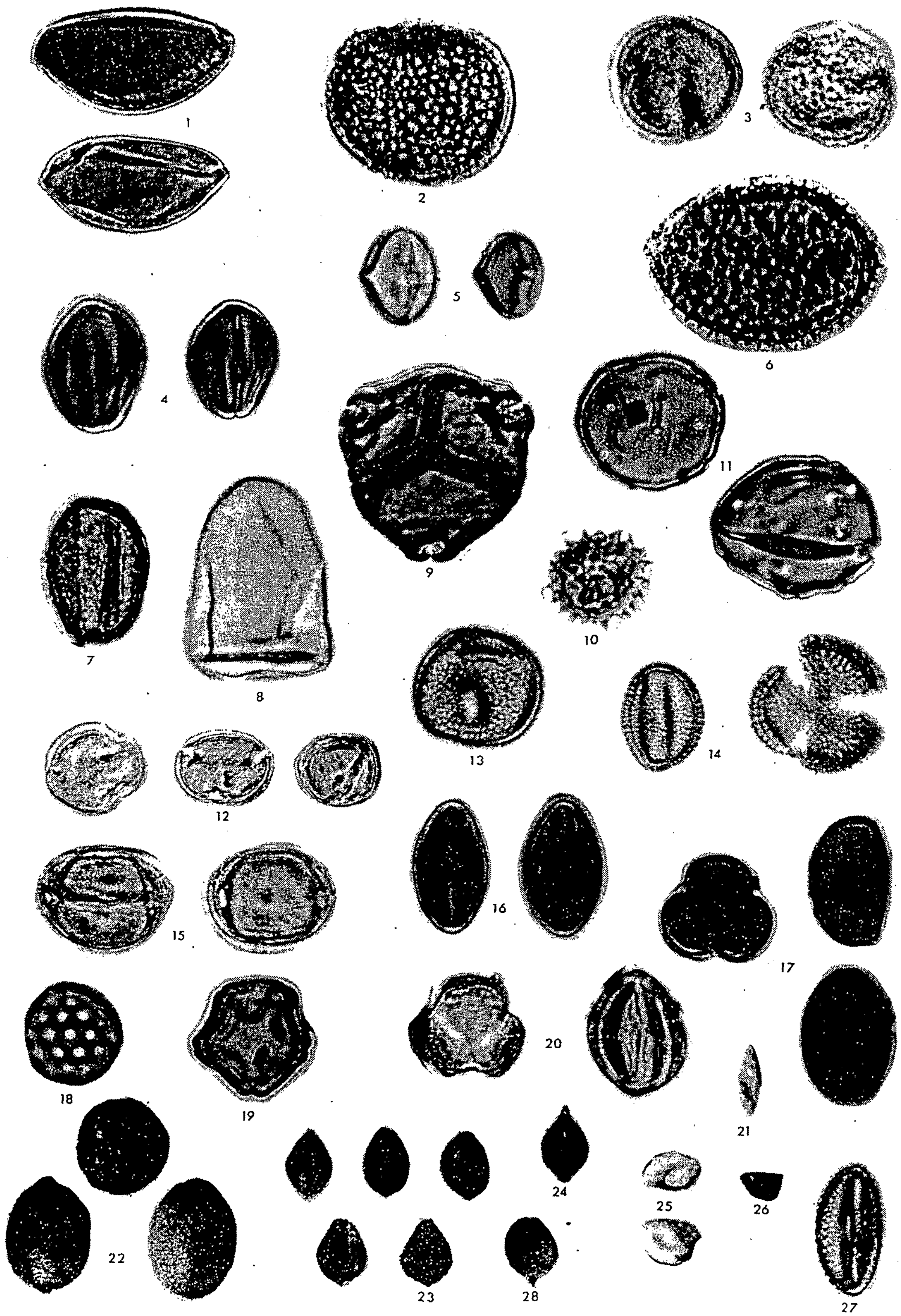

FIGURE 2

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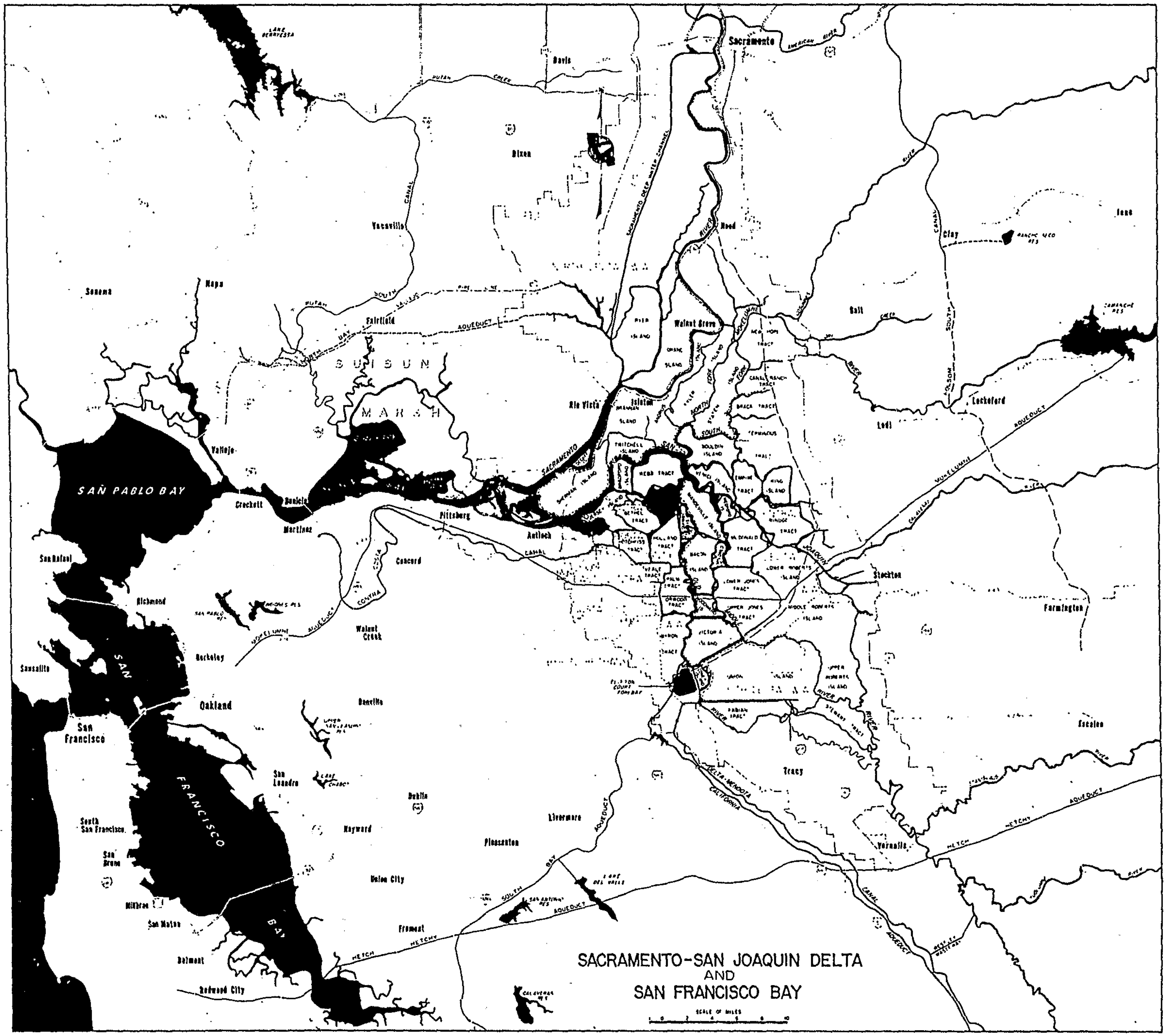

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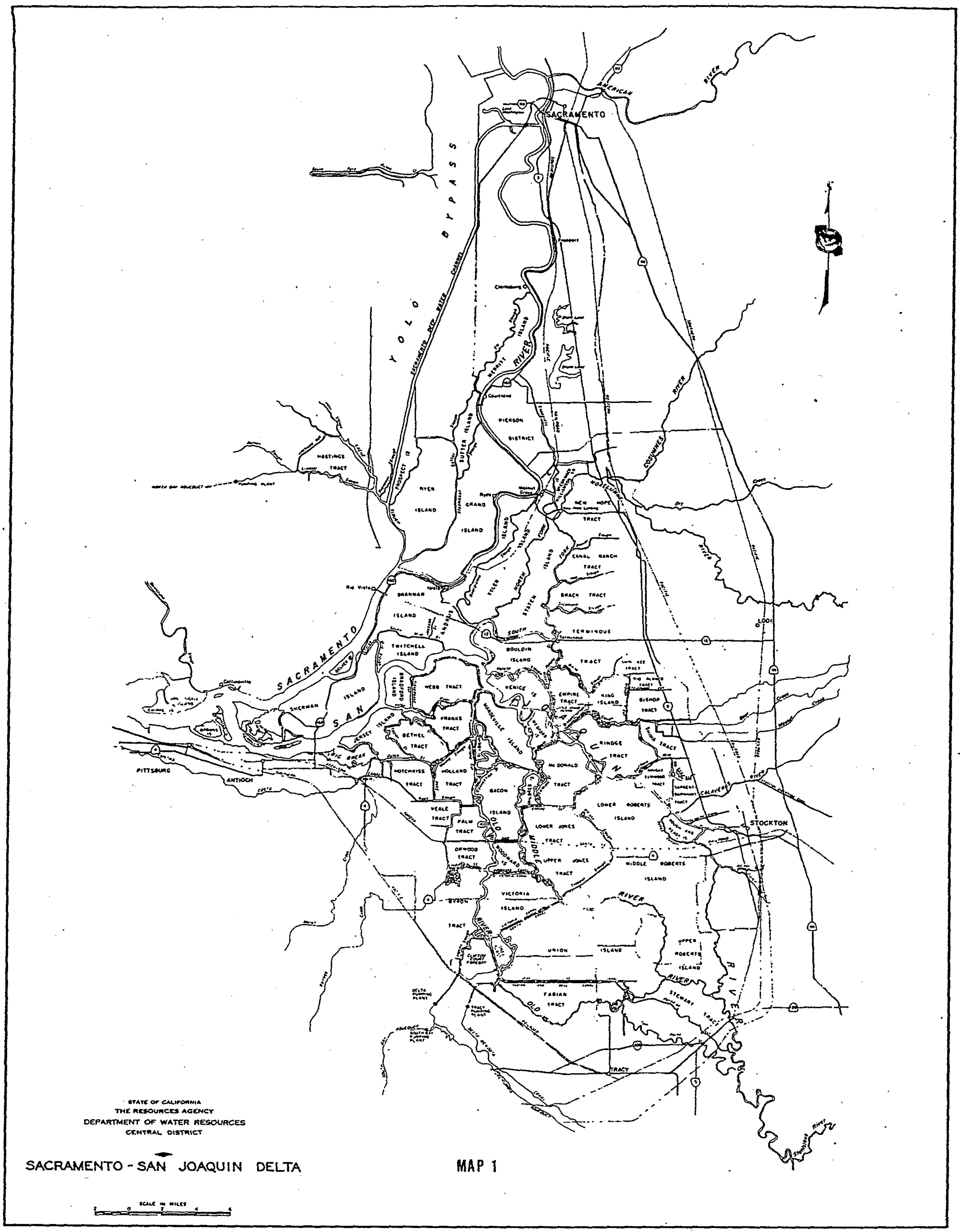

SACRAMENTO - SAN JOAQUIN DELTA

MAP 1

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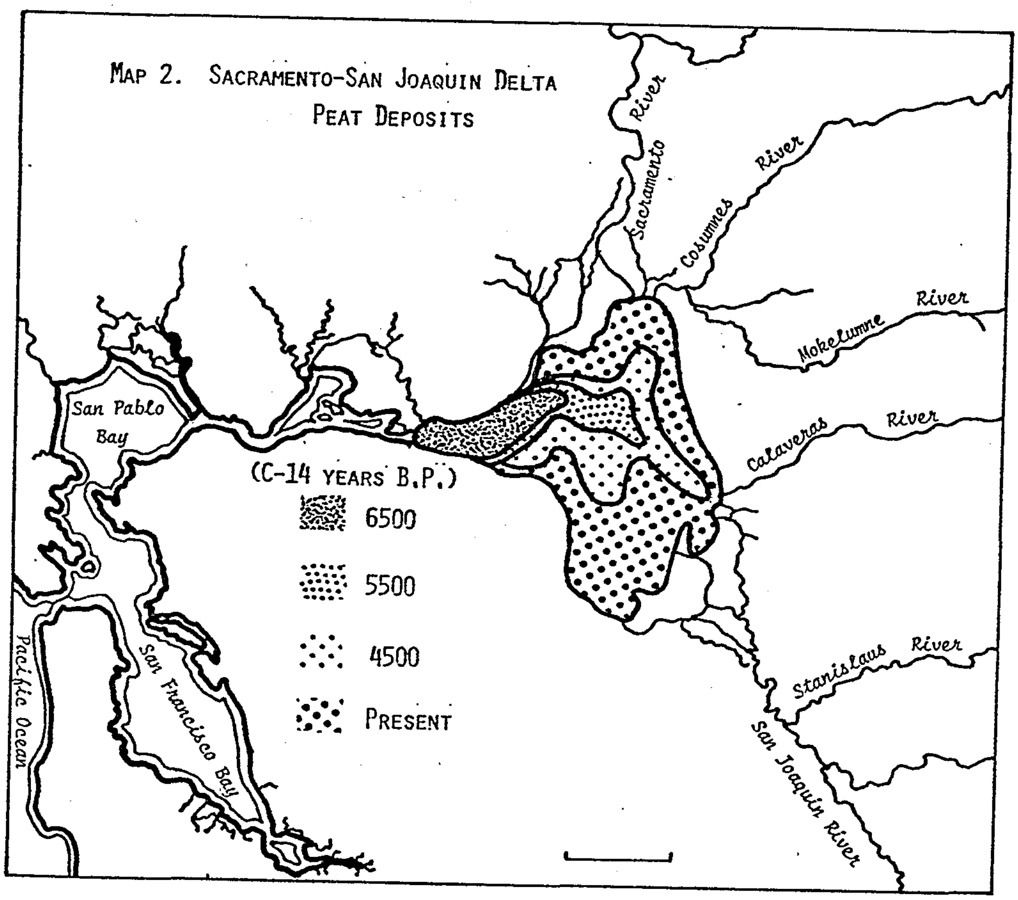
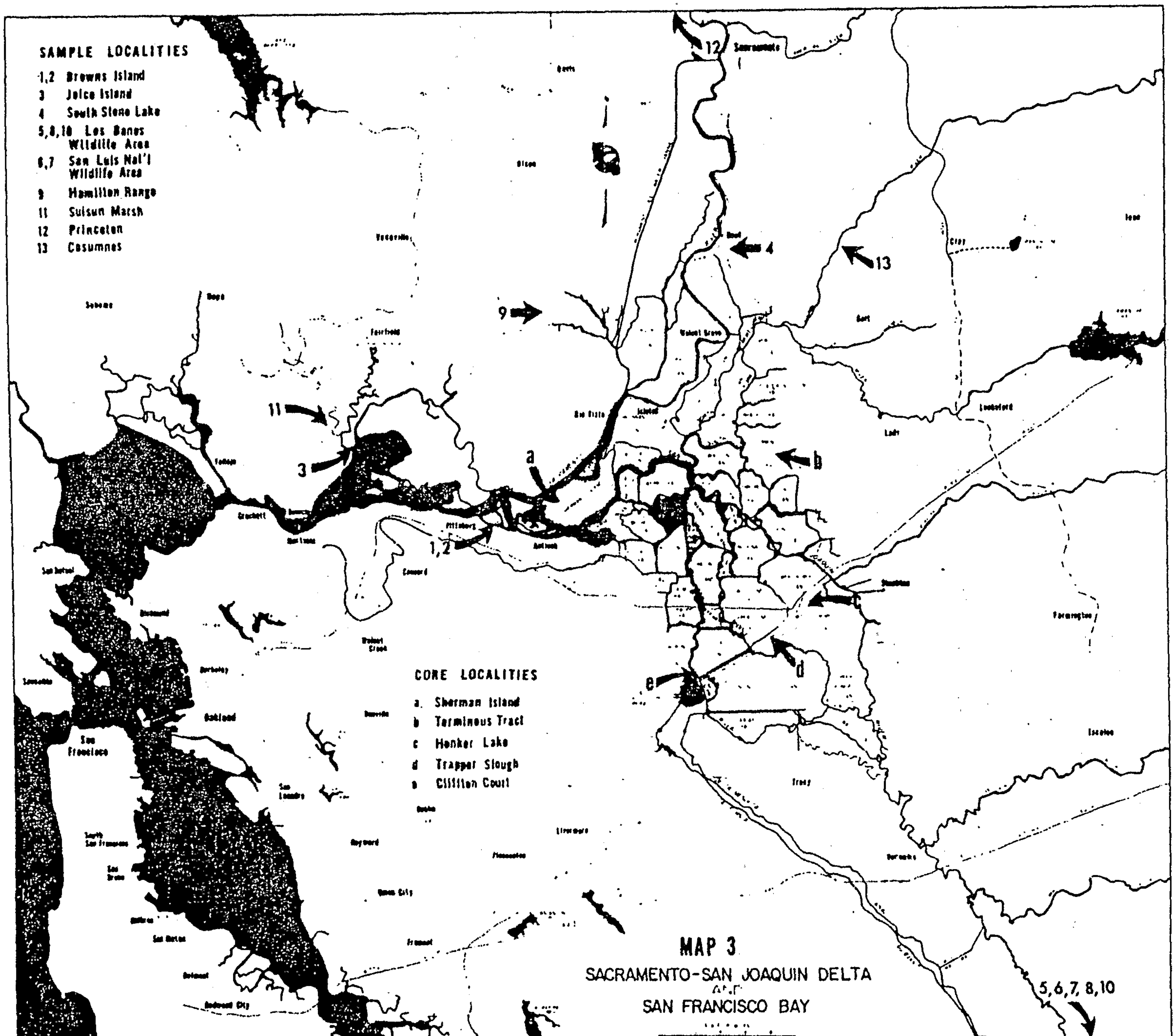
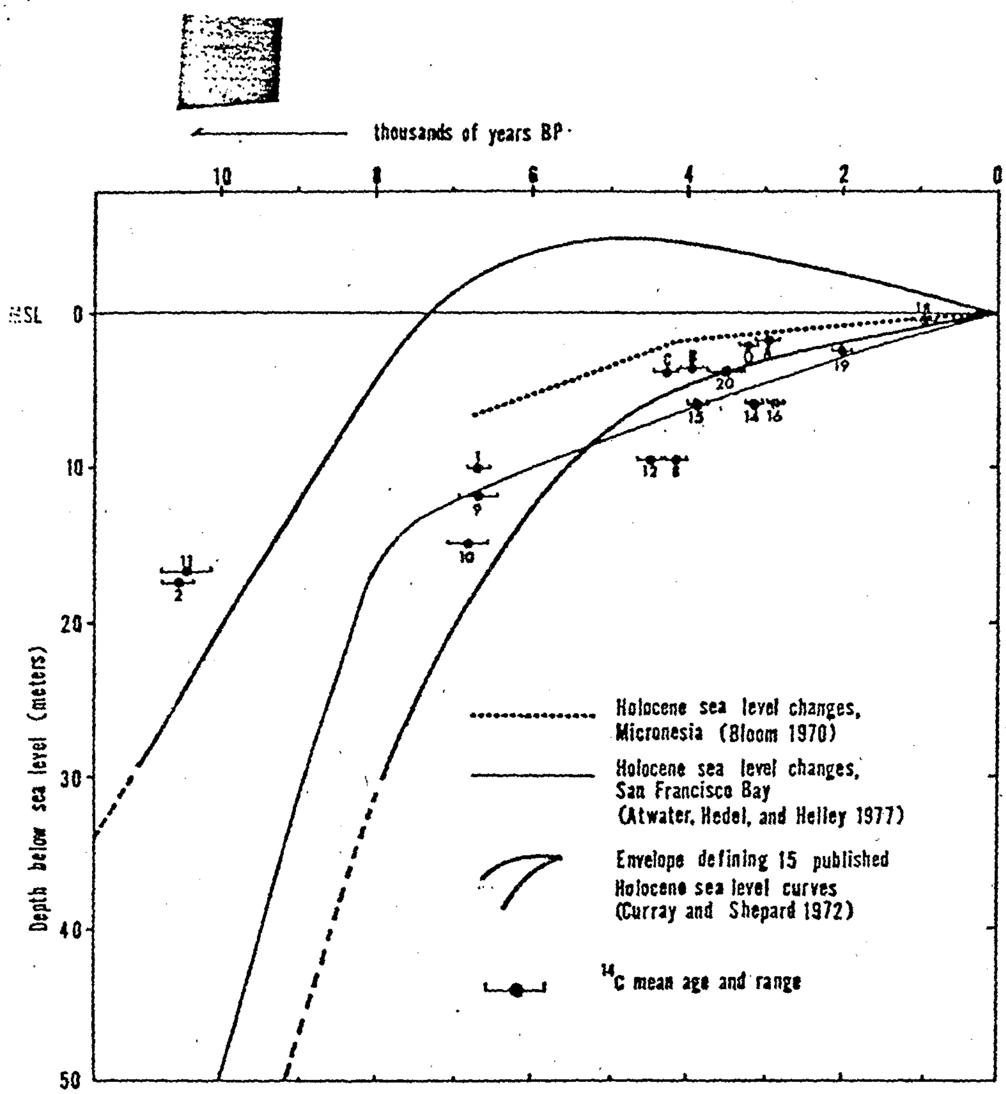


Map 2. Sacramento-San Joaquin Delta
Peat Deposits
(C-14 years B.P.)
6500
5500
4500
Present
San Pablo Bay
San Francisco Bay
Pacific Ocean
Sacramento River
Cosumnes River
Mokelumne River
Calaveras River
Stanislaus River
San Joaquin River


SAMPLE LOCALITIES
1,2 Browns Island
3 Joice Island
4 South Stone Lake
5,8,10 Los Banos Wildlife Area
6,7 San Luis Nat'l Wildlife Area
9 Hamilton Range
11 Suisun Marsh
12 Princeton
13 Cosumnes
CORE LOCALITIES
a. Sherman Island
b Terminous Tract
c Honker Lake
d Trapper Slough
e Clifton Court
5,6,7, 8,10
MAP 3
SACRAMENTO-SAN JOAQUIN DELTA
SAN FRANCISCO BAY


thousands of years BP
10
8
6
4
2
0
MSL
0
10
20
30
40
50
Depth below sea level (meters)
Holocene sea level changes, Micronesia (Bloom 1970)
Holocene sea level changes, San Francisco Bay (Atwater, Hedel, and Helley 1977)
Envelope defining 15 published Holocene sea level curves (Curray and Shepard 1972)
^{14}C mean age and range

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Tbl 3 Clifton Court

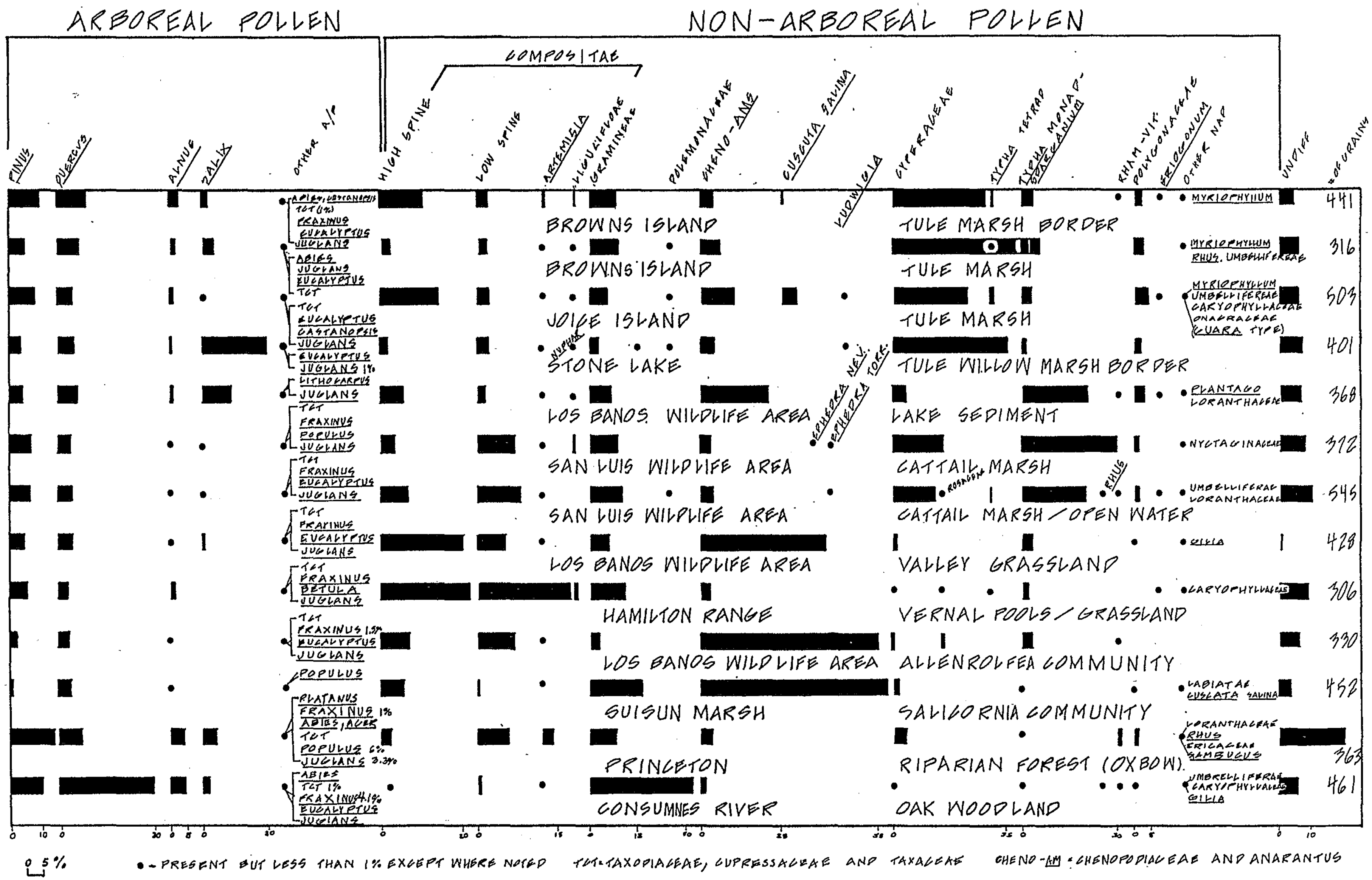
Soil Profile Data

Sample	Depth (inches)	%C	%O.M.	TKN %	N^{15}/N^{14}	Hg µ grams / .5g soil	pH[2/]	B.D.[1/] dry wt. / dry vol.	Textural Class	%clay[3/] <2µ	%clay[3/] <1µ	%total[3/] sands	%silt[3/]
2-1	0- 12	9.85	17.04	0.57	.00367	0.10	4.88	1.05	Organic Clay	68.9	57.4	4.5	26.6
2-2	12- 24	9.54	16.51	0.57	.00367	0.15	4.55	0.85	Organic Clay	69.1	61.0	1.7	29.2
2-3	24- 36	12.91	22.34	0.65	.00368	0.10	4.42	0.5	Muck	---	---	---	---
2-4	36- 48	14.35	24.83	0.70	.00367	0.25	4.79	0.6	Muck	---	---	---	---
2-5	48- 60	0.55	0.95	0.03	.00367	0.70	6.32	1.5	Clay Loam	32.7	30.7	43.2	24.1
2-6	60- 72	0.84	1.46	0.03	.003675	0.35	6.05	1.5	Clay Loam	32.5	29.7	40.2	27.3
2-7	72- 84	2.42	4.18	0.12	.00367	0.25	6.00	1.4	Silty Clay	51.4	44.7	3.3	45.3
2-8A	108-117	2.29	3.96	0.11	.00368	<0.05	5.18	1.2	Silty Clay	53.0	45.7	1.1	45.9
2-8B	117-120	10.54	18.23	0.44	.00367	0.15	2.70	0.8	Organic Clay	71.9	61.3	1.8	26.3
2-9A	120-126	9.69	16.77	0.45	.00367	<0.05	2.98	1.0	Organic Clay	59.8	53.6	2.3	37.9
2-9B	126-132	23.00	39.79	0.86	.00367	0.20	3.10	0.8	Muck	---	---	---	---
2-10A	132-138	7.10	12.28	0.41	.00368	0.25	3.34	1.0	Organic Clay	64.1	56.2	3.1	32.8
2-10B	138-144	1.46	2.53	0.07	.00367	0.45	2.60	1.4	Silty Clay	43.0	39.2	3.2	53.8

1/ Bulk density - gms/cc

2/ Samples dried before determining pH.

3/ Sand, silt and clay analyses not done on samples with more than 20% organic matter.



MODERN POLLEN RAIN OF SELECTED PLANT COMMUNITIES IN CENTRAL CALIFORNIA

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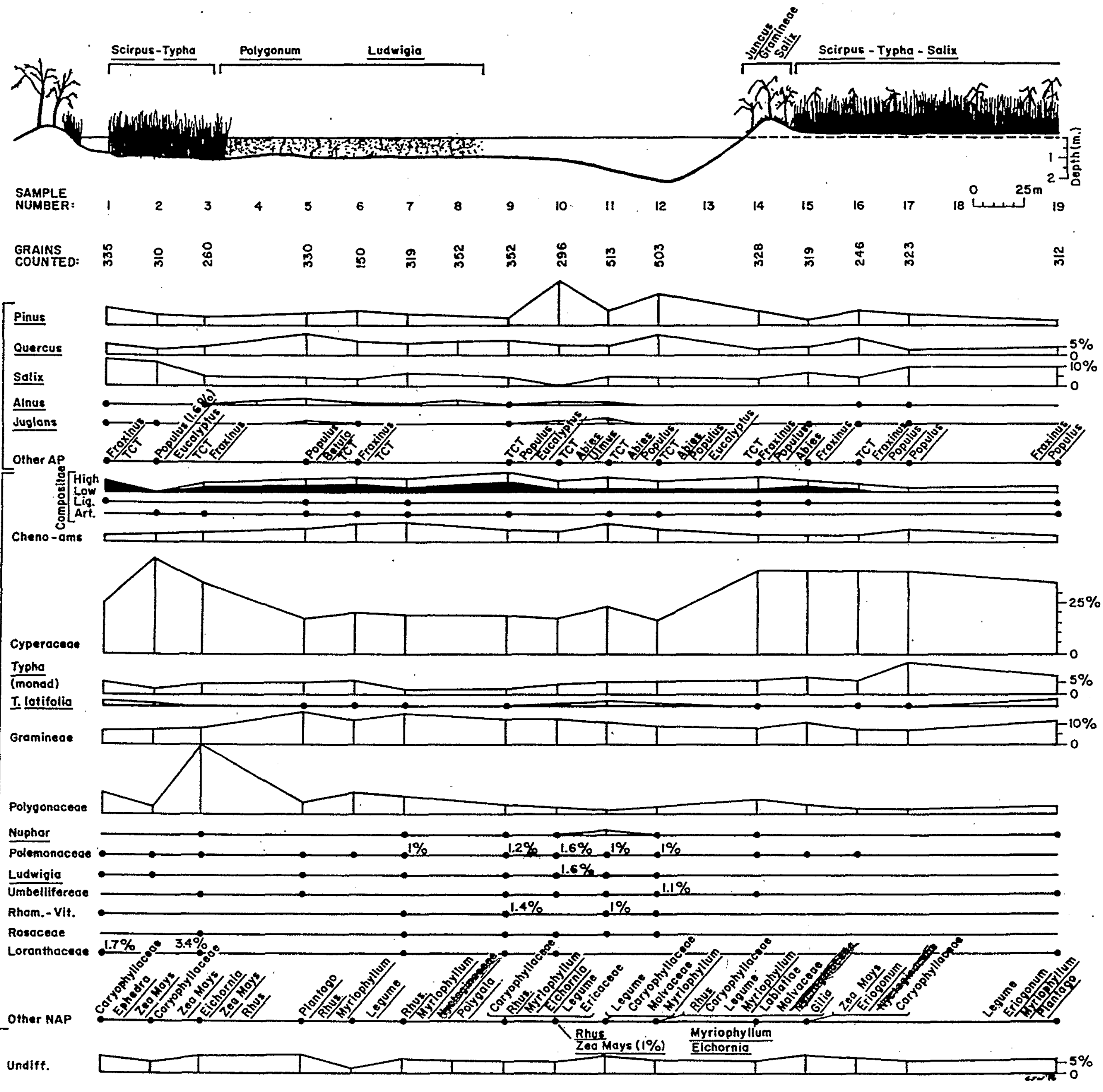
SOUTH STONE LAKE MODERN POLLEN RAIN
SOUTHEAST TRANSECT



●=Present, but less than 1% unless noted otherwise   TCT=Taxodiaceae, Cupressaceae and Taxaceae
Cheno-Ams = Chenopodiaceae and Amaranthus

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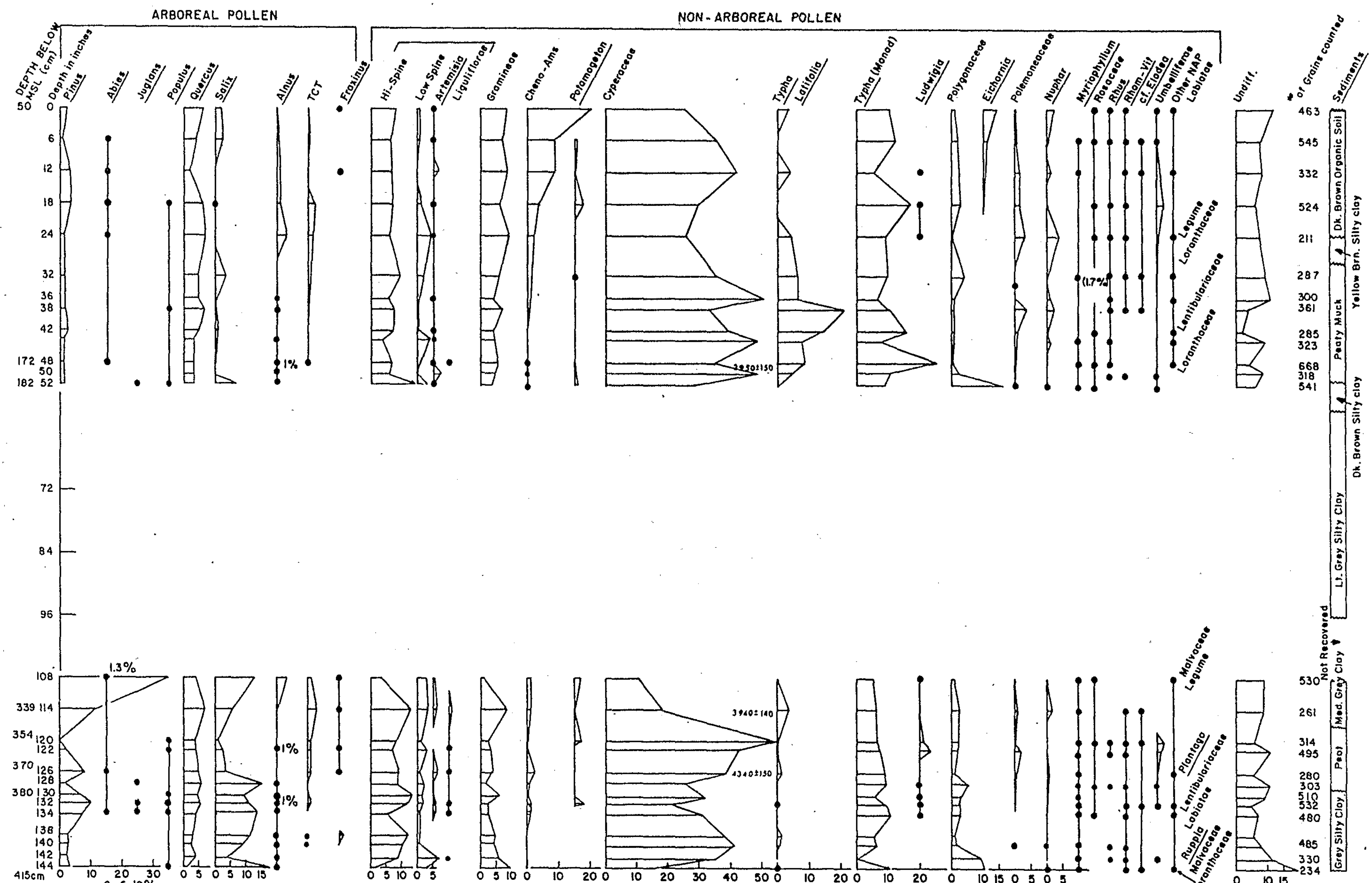

• = present, less than 1% unless noted

TCT = Taxodiaceae, Cupressaceae & Taxaceae

Cheno-Ams = Chenopodiaceae - _Amaranthus_

prepared by: J. West

CLIFTON COURT POLLEN PROFILE, CORE II
SACRAMENTO-SAN JOAQUIN DELTA
CALIFORNIA

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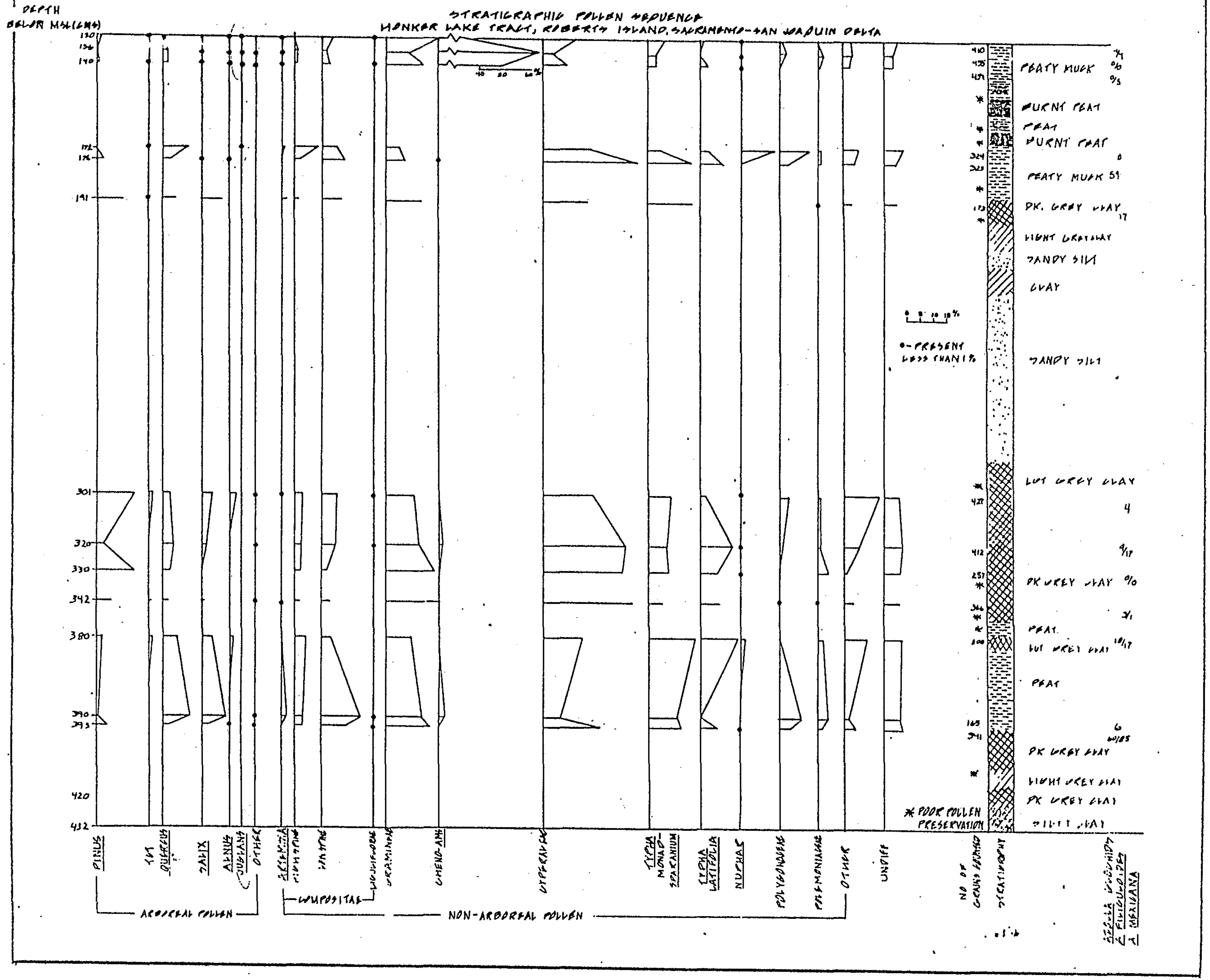
STRATIGRAPHIC POLLEN SEQUENCE
HONKER LAKE TRACT, ROBERTS ISLAND, SACRAMENTO-SAN JOAQUIN DELTA



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